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AIRFIELD DAMAGE REPAIR TECHNIQUES

ENGINEER STUDIES CENTER
US ARMY

Prepared by
412th Engineer Command
for
US Army Engineer Studies Center

July 1981

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This monograph is one of a series prepared under the umbrella of the Engineer Studies Center's study: US Army Engineer Assessment, Europe. It describes the US Army engineer role in the repair of US Air Force air bases in Europe. Included is a description of the circumstances under which US Army engineers will make repairs to runways and taxiways, the current methods of repair, and what repairs will be made under Class A (permanent) and Class B (temporary) constraints. In summary, this monograph shows the preferred repair techniques in priority ranking for Class A, Class B, and spall repair and recommends areas for future study.

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CONTENTS

ABSTRACT

This monograph is one of a series prepared under the umbrella of the Engineer Studies Center's study: US Army Engineer Assessment, Europe. It describes the US Army engineer role in the repair of US Air Force air bases in Europe. Included is a description of the circumstances under which US Army engineers will make repairs to runways and taxiways, the current methods of repair, and what repairs will be made under Class A (permanent) and Class B (temporary) constraints. In summary, this monograph shows the preferred repair techniques in priority ranking for Class A, Class B, and spall repair and recommends areas for future study.

LIST OF ABBREVIATIONS

ADR............airfield damage repair
AFB............Air Force Base
AFR............Air Force Regulation
AFSC...........Air Force Systems Command
APOD...........aerial port of debarkation

CBR............California bearing ratio

DAF............Department of the Air Force
DCSENGR........Deputy Chief of Staff for Engineering

ENGCOM.........Engineer Command
EOD............explosive ordnance disposal
ESC............Engineer Studies Center

FOD............foreign object damage
FRG............Federal Republic of Germany

HN.............host nation

JCCRS..........Joint Contingency Construction Requirements Study
JCS............Joint Chiefs of Staff

MOS............minimum operating surface

NATO...........North Atlantic Treaty Organization

OCONUS.........outside continental United States

POL............petroleum, oils, and lubricants
psi............pounds per square inch

RRR............rapid runway repair

STANAG.........Standardization Agreement

USAF...........United States Air Force
USAFE..........United States Air Force Europe
USAREUR........United States Army Europe

UXO............unexploded ordnance

WES............United States Army Corps of Engineers Waterways Experiment Station
WP.............Warsaw Pact

AIRFIELD DAMAGE REPAIR TECHNIQUES

I. INTRODUCTION

1. Purpose. This monograph addresses the US Army engineer role in the repair (or in support of the repair) of USAF air bases in Europe. It discusses the type of war damage repair that US Army engineer units will probably perform at USAF air bases during a NATO contingency in Europe, and it suggests the most efficient and effective techniques to use in completing these repairs.

2. Scope. This study considers two basic types of war damage to USAF air bases in the rear combat zone in Europe--runway and collateral.[1/] It deals primarily with runway and taxiway repairs, since this type repair is envisioned as the most urgent during the initial days of a war insofar as the Army engineers are concerned. This study looks closely at the technical aspects of ADR, including a discussion of the types of repair and an evaluation of alternative methods.

3. Study Methodology. The study was initiated during September 1979 with discussions between ESC and the 412th ENGCOM to define the scope and purpose. ESC provided additional study guidance to the 412th ENGCOM in January 1980. A literature search was conducted to locate and review the various studies of crater repair that have been prepared in recent years. Annex D is a partial bibliography for the literature review. Early in the study, interviews were held with personnel at the USAF Engineering and

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1/ Runway damage is by far the most important and includes large craters, small craters, spalls, and surface damage on the runway and taxiways. Collateral damage includes war damage to control towers, runway lighting, POL facilities, roadways, aircraft shelters, arrester gear, ammunition and weapon storage facilities, avionics, weapons maintenance facilities, communication systems, electrical distribution systems, and buildings.

Services Center, Tyndall AFB, Florida, and at the US Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. These interviews provided information on both Air Force and Army research in runway repair techniques and added to the literature available to the study team. An OCONUS trip by the study team was made in January 1980. During this trip, the team spent time with the Plans Branch, DCSENGR, Headquarters, USAREUR, Heidelberg, FRG; the 293d Engineer Battalion, Baumholder, FRG; and USAFE engineering personnel, Ramstein AFB, FRG. The 293d Engineer Battalion has considerable field experience with various damage repair techniques. That unit has field tested some of the techniques proposed by WES. The 293d also has considerable data on repair techniques used by other NATO countries. That information was made available to the study team and is briefly described in this report.

4. Assumptions. The study was based on the following assumptions.

a. The Army will continue to have a mission to support the USAF in ADR, to include emergency repairs and follow-on restoration.

b. Due to the level of damages and limited USAFE and HN capabilities, the US Army engineers will have to assume emergency repair missions on airfield runway and taxiway surfaces.

c. Tactical aircraft require an MOS of 50 feet by 5,000 feet and a 25-foot wide meandering taxiway.

d. Nontactical and civilian-type planes require an MOS of 75 feet by 7,500 feet and a 25-foot wide meandering taxiway.

e. Reconnaissance, damage assessment, and selection of the minimum repair area for the MOS will be accomplished within a very short time frame by the USAF.

f. EOD, a critical part of the repair effort, will be accomplished by nonengineer assets.

g. The equipment and materials necessary to make the rapid repairs will be procured and made available at the air bases.

5. General.

a. Background literature.

(1) A review of current literature suggests that very real problems exist within the plans and capabilities of the engineer resources allocated for war damage repair at USAF air bases. The recent JCS Joint Contingency Construction Requirements Studies II (JCCRS II) identified the level of damage anticipated at USAF air bases in Europe. The JCCRS II study also surfaced a number of questions related to war damage repair. For example, what kinds and quantities of war damage repairs require immediate attention, which can be accomplished over a longer period of time, and which of those should be done by US Army engineer units?

(2) DOD Directive 1315.6[2/] outlines the responsibilities for war damage repair of USAF air bases. US Army engineers are responsible for all semi-permanent repairs and restoration of war-damaged facilities at USAF air bases. Also, should USAF requirements for emergency repair and force beddown exceed the capability of organic USAF engineers, the US Army engineers have the added responsibility of assisting the USAF in performing these tasks.

(3) The current threat analysis as presented in a draft of STANAG 2929[3/] and specific study guidance from ESC (dated January 1979)[4/] were used as the basic criteria in evaluating the required ADR.

2/ DOD Dir 1315.6, Responsibilities for Military Troop Construction Support of the Department of the Air Force Overseas. (For complete bibliographic information on this document, and those following, see Annex D.)

3/ NATO, NATO STANAG 2929--Airfield Damage Repair.

4/ DA, USACE, OCE, ESC, Study Guidance for Air Force Support Study.

b. Essential ADR mission elements.

(1) Reconnaissance/damage assessment.

(2) EOD.

(3) RRR.[5/]

(4) Collateral damage repair to the following.

(a) Operational facilities.

(b) Communication systems.

(c) Ammunition storage facilities.

(d) Essential maintenance facilities.

(e) Fuel storage and distribution.

(f) Utilities.

(g) Access routes (on and off base).

(5) Semi-permanent/permanent runway repair and restoration.

c. UXO. UXO disposal at USAF air bases poses a significant problem. Critical air bases are assigned only a limited number of USAF EOD personnel. If there are numerous UXOs in the operating area to be repaired, the USAFE EOD personnel capability will be greatly exceeded. However, this report does not address EOD requirements, although this is recognized as a major potential problem area. It should be noted that the engineer units supporting an air base do not have the organic capability to handle EOD requirements.

d. Collateral damage. In addition to repair of paved surfaces as discussed above, the Army is also responsible for assisting the USAF in repairing critical air base support facilities. The USAF Prime Beef teams will perform the temporary emergency repairs and the Army engineers will perform the semi-permanent and permanent repairs. The methods of repair for

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5/ RRR is the primary focus of this report.

collateral damages are basically the same as normal engineer construction techniques that are within the capability of the combat heavy battalion. Discussion of these missions and methods of repair is not included as part of this study.

II. ALTERNATIVE REPAIR TECHNIQUES

6. Current Methods of Repair.

a. The current USAF method for emergency repair of craters uses AM-2 aluminum matting placed after the crater has been filled with ejecta and 12 inches of select fill. Computer simulations conducted by the USAF[6/] have predicted roughness problems with the AM-2 mat system when used by tactical aircraft. The AM-2 mat system is a temporary repair and can withstand only limited use.

b. The US Army engineers' only established method for temporary repair of craters is with the use of the AM-2 mat. However, the Army has no AM-2 mat in the supply system. The Army does have the XM-19 mat authorized for use; however, its availability is limited and many problems exist in using this mat for crater patches.

c. The Geotechnical Laboratory of WES is researching certain techniques for temporary repairs and some of these have been field tested by the 293d Engineer Battalion at Baumholder, FRG. Planning efforts of US Army engineers have been directed toward semi-permanent or permanent repair methods such as asphalt or concrete. These methods may require more time and manpower than will be available in a post-attack environment, especially in view of the potential for repeated attacks. These methods also depend on the availability of specialized materials.

7. Repair Conditions and Criteria.

a. General.

(1) Under the current threat analysis of WP forces, extensive damage to air base facilities is expected, and the damage can be repetitive.

6/ DAF, AFCS, AF Weapons Lab, Computer Program for the Prediction of Aircraft Response to Runway Roughness.

This study subdivides the damage to runways, taxiways, and hardstands into three categories: large craters whose depths exceed 3 feet with a diameter of about 60 feet; small craters with depths less than 3 feet and a diameter of 20 feet; and spalls. Spalls are small craters that do not completely penetrate the pavement. Collateral damages that may be associated with an attack include damages to POL facilities, roadways leading to and from the POL facilities, electrical and lighting systems, and buildings.

(2) The first priority of repair at a tactical air base is to restore a minimum 50-foot by 5,000-foot tactical aircraft landing strip within 4 hours. Follow-on tasks are to provide an additional 50-foot by 5,000-foot tactical aircraft strip and to upgrade the initial emergency repair to a more permanent standard. At APODs, the initial priority is to restore a minimum 75-foot by 7,500-foot landing strip for reception of nontactical and civilian aircraft. Upgrading of the initial emergency MOS should be accomplished as soon as possible. The initial 4-hour time frame includes the necessary initial UXO disposal and times needed to complete small and large crater repairs.

(3) Class A and Class B are the two basic repair categories used in this study. Each of these methods is considered separately for USAFE tactical air bases and the civilian APODs that handle nontactical aircraft. Class B repairs are those rapid, expedient repairs that provide a temporary surface able to withstand at least 24 hours at NATO maximum rates of sortie generation for tactical aircraft. These types of repair should be upgraded as soon as time and scheduling permit. Class A repairs are those rapid repairs that are semi-permanent or permanent in nature and could be expected to endure repeated loadings over a long period of time.

b. Runway conditions. The typical runways and taxiways encountered in Europe will consist of asphaltic concrete overlays in thicknesses from 2 to 8 inches, portland cement concrete pavement in thicknesses from 4 1/2 to 12 inches, and base course materials. Base course materials are select materials intended to serve as granular, high-strength layers from 9 inches to as much as 66 inches. The subgrades on which these pavements are placed vary in classification and strength. Gravels, sands, clays, and combinations of these materials can be found in most subgrades. WES research documents indicate that 5 to 25 percent of airfield pavement surface area will be damaged by large and small bombs and other ordnance such as cannon fire. The probable volume of ejecta associated with this type damage could be 6,000 cubic yards, or an average of up to 8 inches deep over the entire runway and taxiway area. It is reasonable to assume that these attacks will be repeated until Allied air superiority is achieved. UXOs, as well as follow-up attacks, will make the initial repair efforts especially hazardous. The possibility of performing these repairs in a chemically toxic environment is also very real.

c. Wheel loading. As discussed earlier, there are different MOS requirements for tactical and nontactical aircraft. For purposes of this study, the wheel loadings for various aircraft are subdivided into two basic categories--tactical and nontactical. (Figure 1 shows some specifications for one representative-type tactical and one representative-type nontactical aircraft.) The F4C-type aircraft is referred to as the typical tactical aircraft. The nontactical or cargo-type aircraft include the C5A, C141, C130, and civilian-type aircraft such as the DC-10, 747, and L1011. The C141A is considered the typical nontactical aircraft, since its wheel configuration and loadings are considered the most critical for pavement loading.

SPECIFICATIONS FOR REPRESENTATIVE TACTICAL AND CARGO AIRCRAFT

Aircraft	Max Takeoff Weights (Kips)	Design Loads (Kips)[a]	Contact Area (Sq In)	Tire Pressure (psi)	Main Gear Load (Kips)[b]
F4C (Tactical)	59.1	26.0	102	255	26.0
C141A (Nontactical)	316.6	149.5	208	180	149.5

SOURCE: DA and DAF, jointly, TM5-330 and AFM 86-3, Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations.

a/ Design loads for each wheel of the main landing gear.
b/ For each of two wheels.

Figure 1

d. Weather effects. In addition to time constraints and the type of aircraft (i.e., tactical or nontactical) that will use the runway, weather is also very critical in crater repair. It is critical because it is almost impossible to use ejecta from the crater as fill material during inclement weather such as rain or sleet.

8. Class B Repairs.

a. General. This paragraph discusses the organization and techniques used by the USAF for emergency runway repair using the AM-2 mat and the current USAF research efforts on other repair techniques. It briefly discusses techniques being used by other NATO countries and also covers the various methods investigated for RRR that may be suitable for use by Army engineers. Suitable methods include crushed stone, mat, and regulated set concrete.

b. Methods for USAF.

(1) The USAF has the responsibility to make emergency repairs to the extent necessary to accomplish its air mission. These repairs include a minimum 50-foot by 5,000-foot runway and a 25-foot wide meandering taxiway. The USAF intends to perform this mission with contingency force Prime Beef Teams CF-1 and CF-2, which form a 91-man RRR force manned by 5 officers and 86 pavement maintenance specialists and equipment operators. During peacetime these teams work as part of the Base Civil Engineering Squadron and perform maintenance for pavement, heating, plumbing, refrigeration, and buildings. The composition and specialties of the individuals included in these teams are listed in Chapter 2, AFR 93-3.[7/] The AM-2 mat repair method is the current method of RRR used by the USAF. It is described in detail in AFR 93-2[8/] and is summarized below.

(a) Ejecta greater than 12 inches are pushed off the runway.

(b) The "heaved lip" in the pavement around the crater is removed.

(c) The crater is filled with ejecta to within 12 inches of the runway surface and is lightly compacted with a dozer.

(d) At least 12 inches of select fill is then added and compacted lightly with a dozer to achieve a CBR of at least 4.

(e) Sufficient AM-2 mat with edge ramps is assembled, pulled over the filled crater, and secured to the runway.

7/ DAF, HQ, AFR 93-3, Air Force Civil Engineer Prime Beef Program.
8/ DAF, HQ, AFR 93-2, Disaster Preparedness and Base Recovery Planning.

(2) The 91-man Prime Beef team is trained to repair three large craters per 4-hour period. The AM-2 mat is prepackaged in kits that contain all ancillary items and tools necessary to facilitate their use. The number of AM-2 patch kits available to the team controls the total number of achievable crater repairs.

(3) The USAF research facility at Tyndall AFB, Florida, is working to develop additional ways to repair damaged pavement. The current USAF method described above may prove to be outmoded in light of the current threat analysis. AM-2 does not make an efficient repair material for airfields extensively damaged with small craters (less than 20 feet in diameter). The USAF is also concerned that AM-2 mat repair may cause structural damage to aircraft because the 1 1/2-inch thick mat lies on top of the pavement surface, thereby creating a bump. According to the Air Force Engineering and Services Center at Tyndall AFB, one of the most promising systems being studied is the crushed limestone repair method.[9/] This crushed-limestone method involves refilling the crater with ejecta topped with a single lift of well-graded, high-quality crushed limestone 24 inches thick. It is then compacted only from the surface with 32 passes of a 10-ton vibratory roller. USAF tests have shown that pavement repaired by this method can successfully carry F-4 and C141A aircraft wheel loads. Further tests are underway to minimize the lift thickness, number of compactor passes, and to develop an FOD cover. (FOD is caused by the ingestion of foreign objects into jet engines and by the foreign objects causing external damage to the aircraft.) There are two factors which bear unfavorably on using this method of repair.

9/ This repair method is based on the prior provision of an adequate supply of crushed stone stockpiled adjacent to the runway. The analysis considers a typical crater as shown in Annex A.

(a) The USAF has only a very limited number of 10-ton vibratory compactors.

(b) USAF operations personnel are not currently being trained in the crushed stone method of repair.

c. Methods for Army engineers--tactical aircraft.

(1) For tactical aircraft, the AM-2 mat method and the crushed stone method are available for Class B repairs. Army documentation describes the crushed stone method somewhat differently from that described above for the USAF. The Army procedure[10/] is described below.

(a) Separate the ejecta; remove all ejecta greater than 12 inches and push it to the side of the runway.

(b) Fill the crater to within the required thickness with ejecta smaller than 12 inches in diameter and compact lightly with a dozer and vibrator.

(c) Place crushed stone in a concave lift procedure with 12-inch lift thickness whereby each 12-inch lift terminates at the surface and facilitates the entrance and exit of construction equipment into the crater.

(d) Compact each of the lower lifts with vibratory rollers to 95-percent CE55 modified density. The top 12-inch lift is compacted to 100 percent or greater of CE55.

(e) Overbuild the final lift by 2 to 3 inches and compact with the heaviest rubber-tired roller available (eight roller passes should suffice).

10/ DA, USACE, OCE, WES, Airfield Damage Repair.

(f) Blade off and compact again with four passes of the 50-ton roller. If no 50-ton roller is available, the heaviest available roller should be used.

(2) The required thickness of crushed stone is a function of the type of foundation. For a weak clay material, 24 inches are required; for a high clay granular mixture, 16 inches are required; and for a high clay granular material with low fines, 12 inches will suffice. In most cases, if there is a question as to the kind of foundation, 24 inches of crushed stone should be used. Figure 2 gives the minimum required thickness for various foundations for tactical and nontactical aircraft.

MINIMUM THICKNESSES FOR
CLASS B CRUSHED STONE REPAIRS

Foundation Strength	Aircraft	Crushed Stone[a/] (inches)
Weak clay material	F4	24
	C141 and F4	38
Medium clay, granular mixture	F4	16
	C141 and F4	21
High clay, granular, low fines	F4	12
	C141 and F4	15

a/ See Annex C for gradation of crushed stone.

Figure 2

(3) The crushed stone method of rapid repair requires changes when inclement weather exists. Water in the crater can be pumped out prior to the repair. However, if heavy rains occur during the repair process, the

ejecta will become unusable as fill material in the crater. If the ejecta turns to mud, no bearing can be obtained with the crushed stone. One alternative construction method in inclement weather is to pump the water from the crater and fill the entire crater with the crushed stone. Another alternative is to line the crater with an impervious membrane, fill the lower portion of the crater with large rocks (3 to 5 inches in diameter), and then fill the remainder with compacted crushed stone. All ejecta must be removed from the runway.

(4) The crushed stone surface will require an asphalt tack coat with a sand blotter to eliminate FOD. The surfacing layer can be placed with an emulsified asphalt sprayed with a distributor spray bar or a portable sprayer at the rate of 0.1 to 0.3 gallons per square yard. The sand blotter can be spread by personnel using hand tools.

(5) This type of repair will last for an extended period of time if the repaired craters are observed after use and necessary repairs in the form of additional stone and compaction are made when needed. This repair technique could be expected, with minor maintenance, to last for several days or until the combat situation would permit semi-permanent or permanent repairs. Annex B shows a cross-section sketch of a crushed stone repair technique with tack coat.

(6) The AM-2 mat could be used by the Army engineers if it were available to them. Presently, however, there are only minimal stocks in the Army Supply System. The study team considered the use of XM-19 mat that is in the Army Supply System. However, there are no end ramps available for the XM-19 mat, and tactical aircraft cannot handle the abrupt change in runway elevation that the lack of end ramps would cause. Also, there is presently no

tiedown system designed for the XM-19 mat. Therefore, for practical consideration, XM-19 mat is not a reasonable option to Army engineers for rapid crater repair for tactical aircraft.

(7) Regulated set concrete has been tested as a rapid repair technique and has proven difficult to use because of the unpredictable setting time, the skill requirements for the personnel placing the concrete, and the availability of materials and specialized equipment at the time and place needed. Asphalt and concrete caps take longer to construct and are discussed later in paragraph 9 of this section under Class A semi-permanent and permanent repairs for tactical and nontactical aircraft.

d. Methods for Army engineers--nontactical aircraft.

(1) The crushed stone method of repair as described above is suitable as a Class B repair technique for nontactical aircraft at APODs. The thickness of stone required varies with the foundation strength and should be as shown in Figure 2. Requirements for thicknesses of stone are greater for nontactical aircraft and range from 15 to 38 inches. Compaction should be in 12-inch lifts as described in paragraph 8c for tactical aircraft. When foundation conditions are unknown, 38 inches of crushed stone should be used. If rain makes use of ejecta impossible, the entire crater could be filled with stone. Use of an impermeable membrane liner should also be considered.

(2) Mat provides a second option for nontactical airfields. The AM-2 mat would not likely be available to the Army. However, the XM-19 mat in the Army Supply System can be used since cargo-type aircraft are not affected significantly by the 1 1/2-inch bumps produced on the runway and, hence, the lack of end ramps is not a problem. Based on discussions with design engineers at Douglas Aircraft Company, civilian aircraft such as the DC-10, Boeing

747, and L1011 would not be adversely affected by the uneven surface except for possible tire damage. The repair procedure would be very similar to that the USAF uses with the AM-2 mat. The bridging characteristics of the XM-19 mat are as good as the AM-2. Use of the XM-19 mat as a patch is not discussed in the literature, but WES research personnel indicate that it would be a totally acceptable repair technique. A problem with lateral stability of the mat will occur if the pilot applies the brakes while crossing the mat. However, the same problem exists with the AM-2 mat because the grouted anchor system will not hold under the braking force of a C141 or other cargo-type aircraft.

e. Small crater repair. The techniques for repairing small craters are the same as for large craters. Compaction is more difficult in a small crater due to the large size of the equipment being used. It is estimated that a small crater repair will require 75-80 percent of the time and effort required for a large crater repair.

f. Spall repair. Spalls or small craters that do not completely penetrate the pavement will be numerous throughout the area of runway/taxiway being repaired. The repair of spalls does not lend itself to a Class B repair to be upgraded later. Spall repairs will be discussed in the Class A repair portion of this report since the repair method is the same for Class A and Class B.

g. ADR repair in other NATO countries.

(1) FRG. Primary responsibility for ADR belongs to the Luftwaffe Engineers and secondly to the Territorial Army. The FRG uses AM-2 mat patches and a rapid or emergency repair technique similar to that of the USAF.

(2) Great Britain. The primary responsibility for ADR belongs to the British Royal Engineers. Their emergency repair technique involves filling the crater with rock and using a mat patch. The mat, a Class 60 trackway in panels that are fitted together, is stored in rolls. It differs from the AM-2 but has the same capabilities. Select fill material is currently stockpiled along the runway. The British also use a self-propelled pavement breaker to assist in crater preparation.

(3) France. The French repair method includes trimming the crater edges to form a rectangular area. The crater is filled with rock to the level of the surface. A pierced steel mat patch is pulled into place and sunk flush with the adjacent pavement by using a vibratory roller. Cold bituminous pavement is used to join the mat to the pavement.

9. Class A Repairs.

a. General. This paragraph discusses semi-permanent and permanent repair techniques. These repairs are not constrained by the rigid time requirements under emergency or rapid repairs. The USAF has no Class A repair mission, since these responsibilities are assigned to the Army engineers. The techniques available include the use of concrete, asphalt, and the crushed stone used for Class B repairs. It is assumed that as soon as the combat situation permits, the emergency repairs and rapid repairs would be upgraded to Class A. The Class A methods presented differ for tactical and nontactical airfields only in thickness of surface and bearing (see Figure 3). Therefore, tactical and nontactical airfields are not separated for presentation in this section. The type of Class A repair performed will be a function of the construction materials available at the air base. The proven Class A repairs that are available are the crushed stone method, the flexible pavement method, and the rigid pavement method. The minimum requirements for those repairs are also a function of the following.

(1) The foundation material strength.

(2) The type of aircraft. (Figure 3 considers the critical wheel loads for tactical and nontactical aircraft only.)

(3) The type of construction material available for repair as indicated in Figure 3 (which includes the crushed stone requirements from Figure 2).

MINIMUM THICKNESSES FOR CLASS A REPAIRS

Strength	Aircraft	Crushed Stone (Inches)	Flexible Pavement (Inches)	Concrete Pavement[a/] (Inches)
Weak clay material	F4	24	28	14
	C-141 and F4	38	44	15
Medium clay, granular mixture	F4	16	18	13
	C-141 and F4	21	24	14
High clay, granular, low fines	F4	12	14	12
	C-141 and F4	15	18	12

a/ Requires 24 inches of crushed stone base.

Figure 3

b. Upgrading USAF emergency repairs. The AM-2 mat patch placed by the USAF will be removed for reuse, and Army engineers will make semi-permanent or permanent repairs. Since the mat patch requires very little compactive effort, the top portion of the emergency crater fill will have to be removed and replaced with a well-compacted base to facilitate the permanent repair. The same would hold true for a patch if XM-19 or any other type mat were used.

c. Crushed stone method. The crushed stone method of repair was discussed earlier as the most logical Class B repair technique for use by Army engineers. It is basically a temporary-type repair. However, with some maintenance, it can last for an extended period of time. There are some techniques which can be used to make the crushed stone repair more durable.

(1) A well-graded, well-compacted, high-quality crushed stone repair does not require a surfacing layer except for prevention of FOD. Preventing FOD for Class B repairs can be accomplished with an emulsified asphalt sprayed at the rate of 0.1 to 0.3 gallons per square yard and sealed with a uniform sand blotter course.

(2) Better surfaces could be provided to reduce the repairs needed. For example, the top 6 inches of crushed stone can be blade-mixed with 10 percent or more type III PCC or BN 550 high-early strength cement, wetted and compacted for the surfacing layer. If available, high-quality hot-mix asphalt may be placed to a 4-inch minimum depth on top of the crushed stone. A silikal cap placed over the crushed stone is another method that has been tested and will work, but it is probably better suited to small craters. Silikal is an acrylic concrete made in the FRG and is discussed in subparagraph 9h of this section. A uniformly graded aggregate is needed for the top 30 millimeters when using silikal.

(3) When using the crushed stone repair method in inclement weather, additional crushed stone is used instead of ejecta and some form of impermeable membrane such as filter fabric should be used in the bottom of the crater to keep the wet foundation separated from the free-draining crushed

stone. This is a standard procedure used in building roads on soft ground or permafrost areas.

d. Rigid pavement method.

(1) The rigid pavement solution is well documented in research publications. Crater ejecta are removed with a bucket loader and the heaved sections of pavement are pushed out of the crater with a dozer. The crater is backfilled with ejecta and compacted with a dozer or vibrator to achieve a minimum of 85 percent of CE 55 modified density. This is very difficult to achieve, especially in small craters where compaction equipment cannot be used effectively. Therefore, washed gravel or crushed stone can be used to provide a 24-inch base for the concrete cap with considerably less compactive effort. A prefabricated screed pedestal is placed in the center of the crater for use in screeding and finishing the concrete. There are several pedestal designs, but the type recommended, a disc 4 feet in diameter and 1 foot thick, has steel dowel bars. This type has no corners for stress concentrations and has steel dowels for load transfer. A 2-inch by 6-inch deep hole is required in the center for the screed pin. The rigid pavement cap can consist of either high-early strength concrete or type I PCC. Each of these materials has an age versus strength relationship that is influenced by the water-cement ratio, type cement, temperature, humidity, and percent accelerator used. The specific concrete mix that is used will determine the curing time required before traffic is allowed. The concrete must have obtained a 1,500-psi compressive strength before it is subjected to traffic. A time versus strength gain curve must be obtained for any particular rigid pavement concrete mix. About 160 hours of curing time is required before traffic can be

allowed on a rigid pavement patch using BN 250 concrete without accelerators. The BN 550 concrete mix which contains 2 to 4 percent (by cement weight) concrete liquifier (BVF) and 8 percent (by cement weight) accelerator (B-3) will allow traffic in 8 hours. Regulated-set concrete which would allow traffic in 4 hours has been tried, but based on conversations with field people,[11/] it is very difficult to use with engineer troops. It would require highly trained specialists and additional specialized equipment that is quite expensive.

(2) If a rigid pavement repair is being used to upgrade an AM-2 mat patch, the mat can be pulled aside and then pulled back over the partially cured concrete to allow for some traffic during curing of the rigid pavement patch.

(3) It should be emphasized that a high-volume source of dependable concrete and necessary delivery vehicles must be available before this repair technique can be undertaken.

(4) Rigid pavement may also be used to upgrade a crushed stone repair (described earlier). This repair technique requires that some of the crushed stone fill be removed before placing the desired thickness of concrete. This could result in as little as 12 inches of crushed stone remaining. It is essential that the remaining stone be recompacted to its full load-bearing capacity. The top layer of stone should be removed using either a road grader or a dozer with scarifier teeth. The excavated stone should be stockpiled for future use in other areas. In small craters, jackhammers and hand tools may be needed to loosen and remove the stone. Placing the concrete cap requires the same procedures and equipment as described earlier. The

11/ 293d Engineer Battalion, Baumholder, FRG.

runway should not be used until the concrete has developed at least 1,500 psi compressive strength.

(5) Load transfer mechanisms must be installed between the existing runway and the pavement cap.

(6) A self-propelled pavement breaker (such as the Arrow Model D500) is essential to straighten the crater edges, minimize difficulties with obtaining load transfer, and simplify placement procedures.

e. Flexible pavement method. A high-quality hot-mix asphalt can be used as a semi-permanent or permanent flexible pavement repair. Figure 3 shows the required thicknesses which range from 14 to 44 inches. Placing asphalt in these thicknesses with proper compaction in a crater would be difficult, slow, and time consuming. For this type use, a volume production plant must be available in the general area. Delivery could be made using 20-ton dump trucks now in the Army inventory. Heated beds will be required for long hauls. The best use of hot-mix asphalt will be in upgrading a crushed stone repair. As discussed under the crushed stone Class A repair, this could be done with a 4-inch asphalt cap placed during the initial crater repair or during upgrading of a crushed stone repair. The upgrading would include using the scarifier teeth on a dozer or a road grader to break up the stone to about a 6-inch depth with about 4 inches of the stone removed. Compaction of the remaining stone is essential for load transfer and should be accomplished by roller and tamper before placement of asphalt. Care should be taken to ensure that damaged surfacing material around the edge of the crater is removed. The crater edges should be trimmed to provide a clean vertical edge using a self-propelled pavement breaker, jackhammers, air compressor, and hand tools. Irregular shapes will increase the asphalt placement difficulties as a result of physical constraints of the paving machine, and thus increase the placement time to an unacceptable level. The area must be cleared of loose material on the base, including dust and dirt which will interfere with bonding of the prime coat to be applied to the base material. General asphalt procedures are given in TM 5-337.[12/] The standard requirement for a 48-hour curing time for the prime coat may require either elimination of the prime coat or using an RC cutback with faster curing time. The 48-hour delay is not considered acceptable during combat conditions. The prime coat may be eliminated in extremely cold weather. The paving operation includes placing, spreading, and rolling to grade and proper density.

f. Repair techniques in other NATO countries.

(1) FRG. Use of concrete is the preferred method of permanent repair; however, the Germans are researching vacuum drying of concrete. They have some stock of precast paving blocks to place as a surface material.

(2) Great Britain. Concrete is the preferred method of repair; however, the British are researching a method of deep dynamic compaction. This is done using a large weight dropped from about 10 feet. The method is currently used on civilian airfields for foundation improvement and could have some use to Army engineers in upgrading craters repaired by USAF emergency methods.

(3) Netherlands. The Dutch are investigating the use of blast furnace slag as a fill material.

g. Small crater repair. Small craters present several problems in making Class A repairs. Most engineer equipment is too large to be used effectively in the repair, and there has been little study and field testing

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12/ DA, HQ, TM 5-337, Paving and Surfacing Operations.

of repair techniques for small craters. Most of the study and research have involved the large or NATO standard crater. As a result of their training efforts, the 293d Engineer Battalion discovered that there was no definite technique developed for small crater repair and that there appears to be little difference between the times required for repair of small and large craters. The methods of repair for small craters are essentially those that are discussed for large craters--crushed stone method, the rigid pavement method, and the flexible pavement method. The steps in performing these repairs are basically the same as for large craters except smaller equipment is required. The 293d Engineer Battalion found that the 2 1/2-cubic yard loader and the towed airmobile vibratory compactor were about the right size. For the rigid pavement solution, a screed pedestal is not required; but more field testing is needed to fully develop a method for using the screed beam on the smaller craters.

h. Spall repair. One method for repairing spalls that was developed by the British Royal Engineers is placing a 3/4-inch steel plate over the cavity and bolting it in place. A variation of this method developed by the 293d Engineer Battalion involves filling the cavity with concrete and placing the plate over it to protect the fresh concrete. This allows reuse of the plate after the concrete is set. Hot-mix or cold-mix asphalt can also be used. Another method is to fill the cavity with silikal. Silikal comes in separate liquid and powdered components that are mixed at the job site. It sets rapidly and can be used as a wearing surface 1 hour after application. It produces a permanent repair similar to concrete, but with far less curing time. Silikal fumes are quite strong and could require the use of masks and gloves. It does not set well in wet conditions. These factors, plus the requirement for hand placement, limit its potential for large and small craters. Spalls in wet areas could be covered with a canvas and dried with air from an air compressor before the silikal is applied.

III. CONCLUSIONS

0. <u>Class B Repair Techniques</u>.

a. Tactical aircraft. Based on the present day "state-of-the-art" and considering material availability, the crushed stone method with an FOD cover is the best Class B repair method available to US Army engineers.[13/] The AM-2 mat method is an acceptable repair procedure, but the USAF owns nearly all of the AM-2 mat kits and has dedicated them to USAF engineers. Variations of the crushed stone repair method exist since the amount of crushed stone required is a function of the type aircraft and the foundation material. The procedure of placing the full 24 inches and compacting from the top down with 32 passes of a 10-ton or larger vibratory roller may be the least complicated and most rapid method for making an emergency Class B repair. During inclement weather, the best method is to use a membrane or filter fabric to provide a separation between the foundation and the crushed stone and to fill the crater completely with crushed stone. The membrane is not required, but would be helpful. The Army needs to purchase half panels, end ramps, and an anchor system for the XM-19 mat so that it can be used as a mat patch for tactical aircraft. Making these items available would provide a second Class B repair method for Army engineer units.

b. Nontactical (APOD). The crushed stone technique is the best method now available for Class B repair for nontactical aircraft. The required thicknesses are shown in Figure 2. A second (but less satisfactory) method that can be used at APODs for nontactical aircraft is an XM-19 mat patch that could be anchored to the runway with grouted anchors, drilled

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13/ One important fact that should be understood about the crushed stone method is that the material must be a high-quality, well-graded stone that meets the requirements of the gradation band shown in Annex C.

through the mat, and bolted down with oversize washers. XM-19 patch repair could be used on APODs without half panels and end ramps. However, use of this method would preclude use of the strip for tactical aircraft.

11. Class A Repair Techniques.

a. The Class A repair method that the Army engineer unit will use depends on the weather, the availability of materials and delivery systems (i.e., concrete and asphalt production and haul capability), and on whether the repair is an upgrade or a new repair. If it can be assumed that there are no constraints as to materials, costs, and time, the preferred techniques would be ranked as follows for large craters.

(1) Concrete with crushed stone base.

(2) Asphalt over crushed stone.

(3) Continued improvements to crushed stone repairs.

(4) Asphalt without a stone base.

b. If time is critical and no material constraints are imposed, the ranking would be:

(1) Asphalt over crushed stone.

(2) Continued improvements to crushed stone.

(3) Asphalt without a stone base.

(4) Concrete with crushed stone base.

c. If both time constraints and the shortage of both asphalt and concrete exist, then the preferred order would be:

(1) Continued improvements to crushed stone.

(2) Asphalt over crushed stone.

(3) Concrete with crushed stone base.

(4) Asphalt without a stone base.

d. As can be seen from these rankings, the unit performing crater repairs must retain the flexibility in personnel and equipment to perform various types of repairs depending on the situation that exists. The Army (through its own capabilities or by using HN resources) must take steps to ensure that concrete and asphalt are available in the quantities needed and at the locations required for repair. To a certain extent, this is true of crushed stone; however, crushed stone is more adaptable to stockpiling at the air base prior to time of need.

12. Small Crater Repair Techniques. The crushed stone, rigid pavement, and flexible pavement repair methods are acceptable for small craters. As with large craters, the methods will depend on the time constraints and material available. However, since the small crater is less than 3 feet deep, the best repair method is 24 inches of crushed stone compacted from the top with 32 passes of a 10-ton or larger vibratory roller. The FOD cover could be the emulsified asphalt and sand blotter or a silikal cap. Silikal would require more time for placement and may prove difficult to use in the rain.

13. Spall Repair Techniques. Silikal is the preferred method for spall repair. However, if silikal is not available, the second choice is hot-mix or cold-mix asphalt placed in the cavity and rolled with a steel wheeled roller. The last choice would be the use of steel plates. If time permits, type I PCC would be acceptable. Silikal does not perform well when placed under wet conditions. Therefore, some type of canopy or cover and an air compressor would be needed to dry the cavities. In inclement weather, the steel plate may be the only acceptable solution.

IV. RECOMMENDATIONS

14. Summary. Figure 4 provides a summary of the recommended repair techniques that the US Army should adopt for use during the current time frame. The recommendations are listed in order of priority for Class B and Class A repairs for large and small craters and spalls.

RECOMMENDED REPAIR TECHNIQUES IN PRIORITY RANKING

Class B

Method	Tactical	Nontactical
Crushed stone	Preferred	Preferred
AM-2 mat	Not available	Not available
XM-19 mat	Not now usable	Second choice

Class A (tactical and nontactical vary only in depth)

Method	Ranking	Remarks
Concrete	1	Requires more time and materials
Asphalt over stone	2	Requires asphalt plant nearby
Stone with improvement	3	Least materials and time
Asphalt	4	Difficult to use

Spalls

Method	Ranking	Remarks
Silikal	1	Wet weather problems
Asphalt	2	Hot or cold mix
Concrete	3	Takes curing time
Steel plates	4	May need in inclement weather

Figure 4

15. Future Studies. There are a number of studies that the US Army should undertake to increase its capability for meeting its ADR mission requirements. It is recommended that these studies include the following.

a. HN resources. Collection and compilation of HN resources for quarries, asphalt production, and concrete production.

b. Collateral damage. The extent of collateral damage repair required of US Army engineer forces should be quantified in order that force structuring can be realistically accomplished by war planners.

c. End ramps and anchor systems for the XM-19 mat. Needs should be identified based on use of this mat as a patch, and action should be taken to procure the end ramps, half panels, and anchor systems required.

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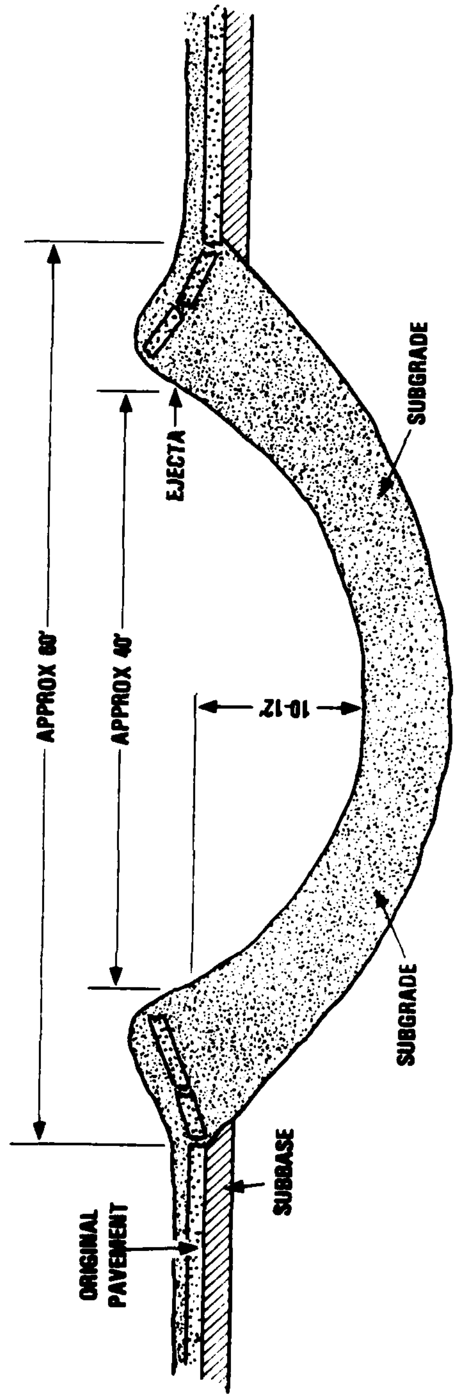
ANNEX A

TYPICAL CRATER

ANNEX A

TYPICAL CRATER



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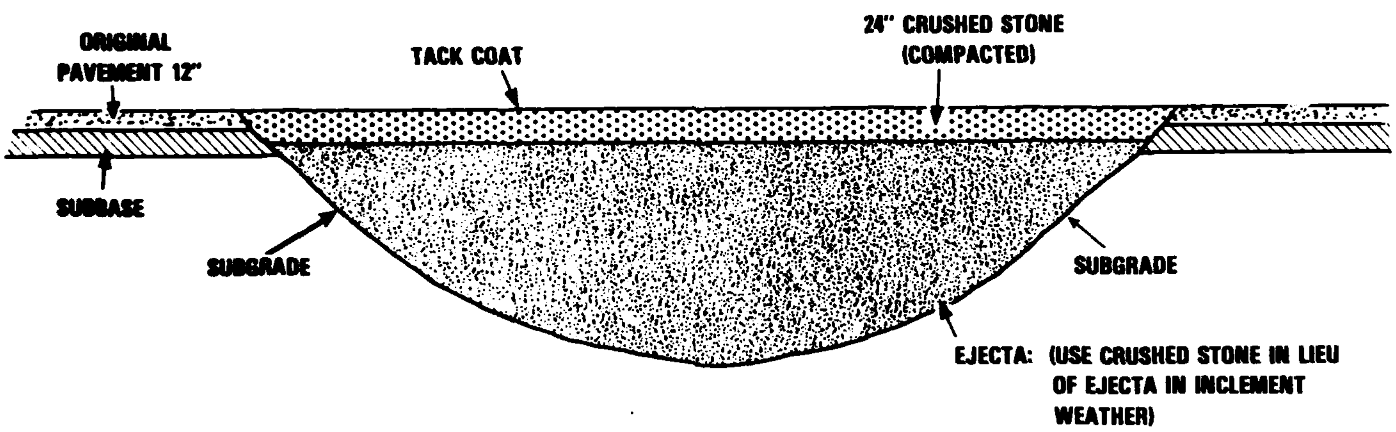
ANNEX B

CRUSHED STONE REPAIR

ANNEX B

CRUSHED STONE REPAIR

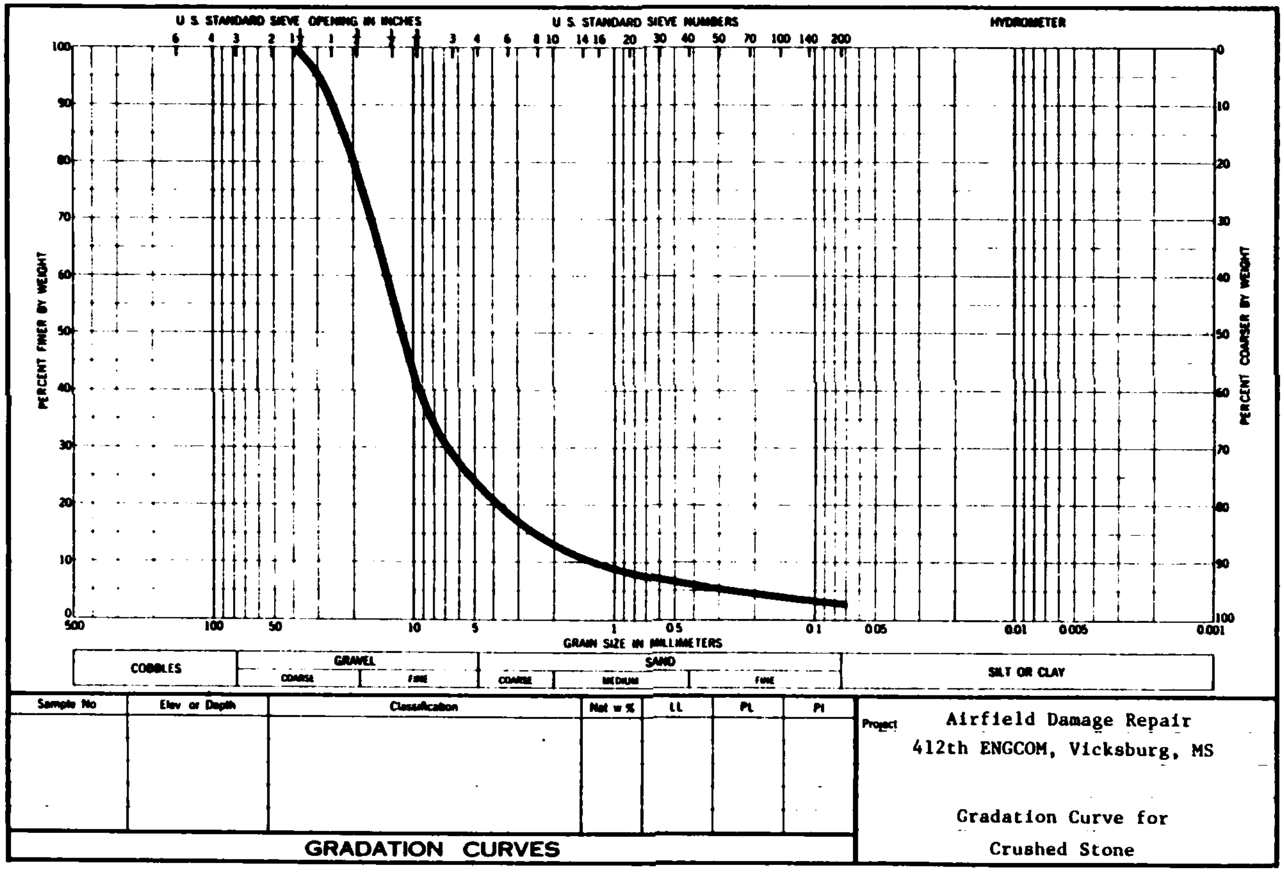


ANNEX C

GRADATION CURVES FOR CRUSHED STONE

ANNEX C

GRADATION CURVES FOR CRUSHED STONE



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ANNEX D

BIBLIOGRAPHY

ANNEX D

BIBLIOGRAPHY

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